Reconstruction in tagger and spectrometer detectors

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April 28, 2022

Far-backward meeting

Introduction

- Geant4 implementation will be shown for taggers and luminosity spectrometer
- Performance of machine learning reconstruction will be evaluated
- Part I deals with taggers, part II describes the spectrometer

Part I: low-Q^2 taggers

Figure: Towards the central detector

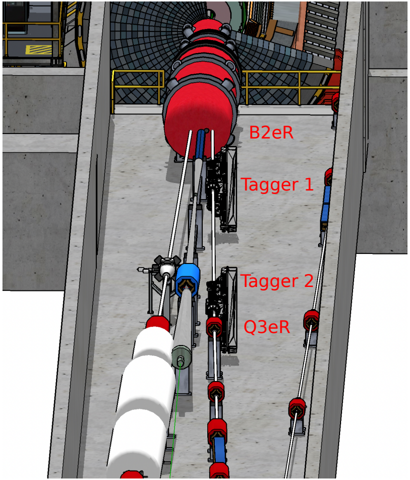
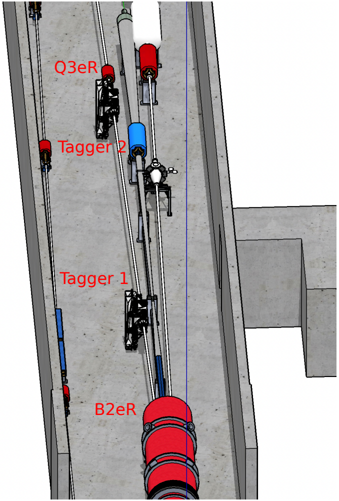


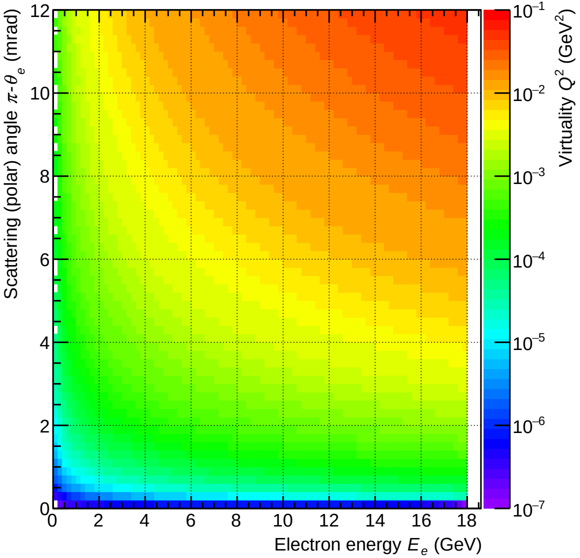
Figure: Towards the tunnel



Electron energy – scattering angle – virtuality

- The Q^2 (color scale) is shown as a function of electron energy E_e and polar angle θ_e
- Polar angle is given in terms of $\pi - \theta_e$ because of negative z for outgoing electrons

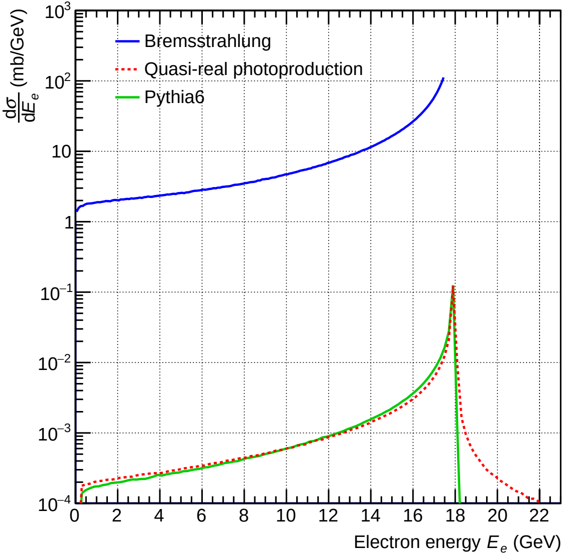
The same virtuality Q^2 is achieved at high energies and smaller angles or opposite – lower energies and larger angles



Cross section as a function of electron energy

- Total cross section is shown for elastic bremsstrahlung and for two models for inelastic *ep* scattering
- Quasi-real photoproduction: Comput.Phys.Commun. 272 (2022) 108251
- Large bremsstrahlung cross section implies a pile-up interaction in each bunch crossing

The bremsstrahlung makes a background in photoproduction measurement



Taggers implementation in Geant4

- Both detectors are implemented as a set of position sensitive planes
- Tagger 1 (closer to B2eR) takes more acceptance at lower energies, opposite for Tagger 2

Figure: Tagger 1

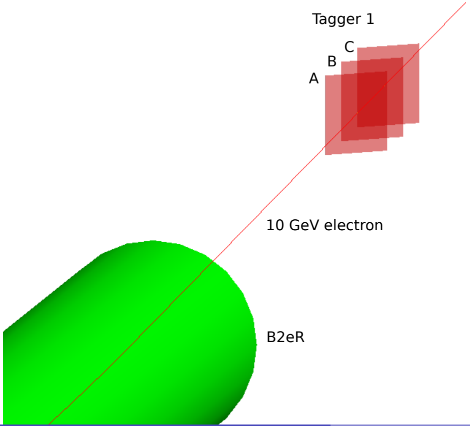
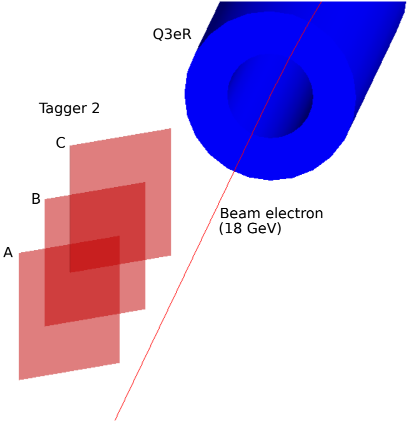


Figure: Tagger 2



Electron reconstruction in tagger detectors

Machine learning algorithm takes track position and angles at the detector (local x, y, θ_x, θ_y) and provides original electron energy E_e and its scattering and azimuthal angles θ_e and ϕ_e

- Energy reconstructed by the algorithm is compared to the true generated electron energy

Figure: Tagger 1

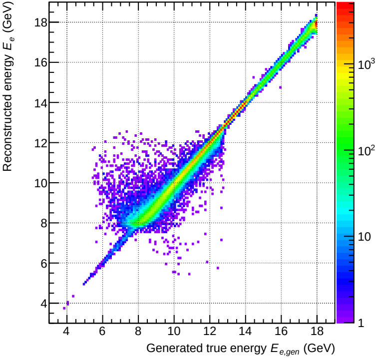
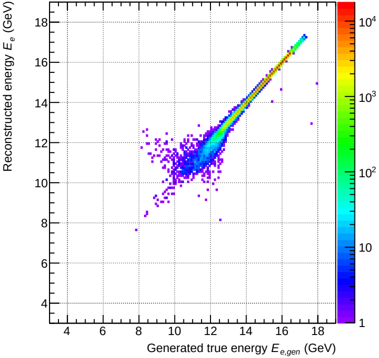


Figure: Tagger 2



Polar and azimuthal angles

Example comparing reconstructed angles to the true generated angles is shown for Tagger 2 (similar performance for holds Tagger 1)

- Beam effects (vertex spread, angular divergence) are included in the simulation
- The true values refer to the values before the beam effects were applied in event generator
- Very small scattering (polar) angles ($\pi - \theta_e < 1$ mrad) are smeared by the divergence
- Reconstruction of azimuthal angle ϕ_e works well away from small polar angles

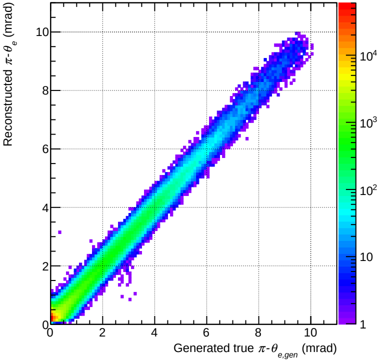


Figure: Polar angle

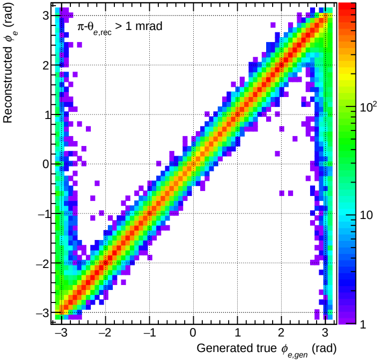
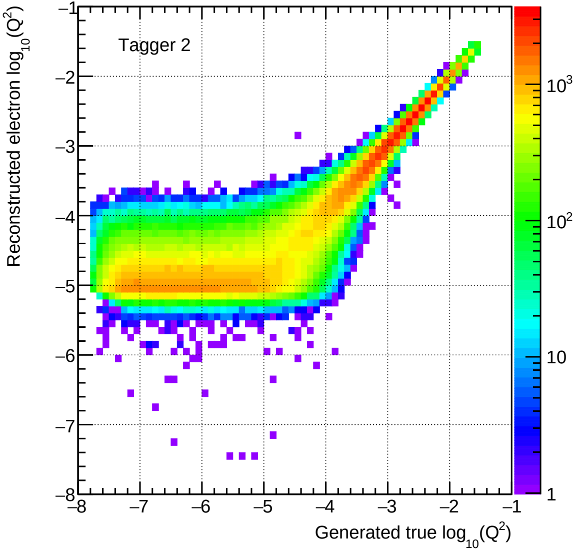


Figure: Azimuthal angle

Q^2 reconstruction

- Reconstructed virtuality Q^2 is compared to generated true event Q^2
- The Q^2 is given by electron energy E_e and scattering (polar) angle θ_e
- Shown for Tagger 2, similar for Tagger 1

Beam angular divergence limits the resolution at $Q^2 < 10^{-3}$ GeV^2



Spectrum of observed Q^2 for bremsstrahlung and photoproduction

- Reconstructed Q^2 is shown for bremsstrahlung and photoproduction (quasi-real and Pythia 6)
- Distributions are normalized to event rates
- True Q^2 for bremsstrahlung in consistent with zero
- Electrons from bremsstrahlung reconstruct to the lowest values of Q^2

Figure: Tagger 1

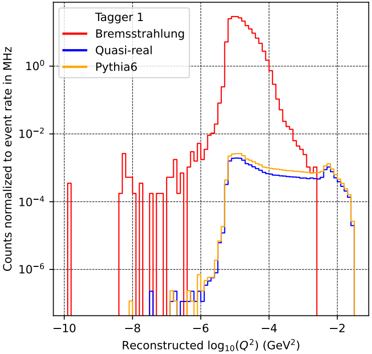
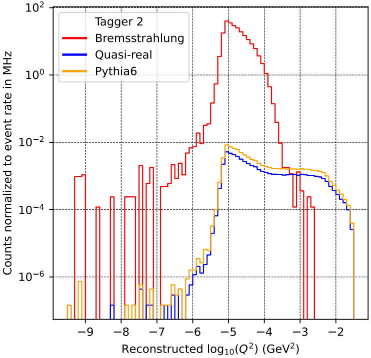


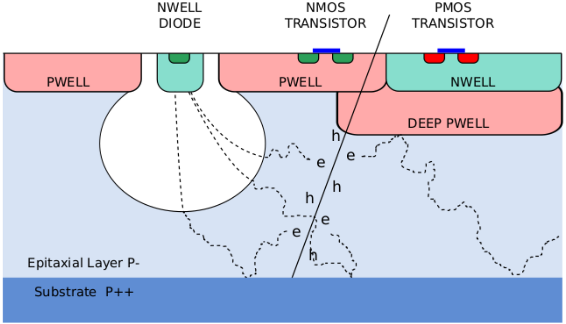
Figure: Tagger 2



Opportunity to extract clean photoproduction signal over a limited interval in Q^2

MAPS as a sensor technology for taggers

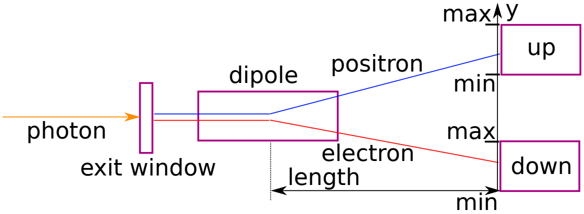
- Signal will be present at every bunch crossing as a result of large bremsstrahlung cross section
- The detector has to separate all individual electron tracks from the same bunch crossing for successful Q^2 reconstruction



- Segmentation for position measurement is ∼200 µm; driven by ability to distinguish separate electron tracks
- Timing response is needed within 1 ns; just to separate individual bunch crossings, no need for precise timing resolution

Part II: spectrometer reconstruction

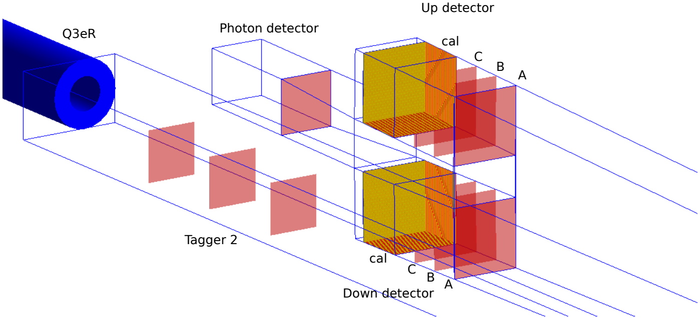
- Tracking layers are placed in up and down detectors
- The same ML algorithm as was used for taggers was applied to photon reconstruction in spectrometer



Feasibility study was done on the use of tracking-only information to reconstruct the original bremsstrahlung photons

Spectrometer implementation in Geant4

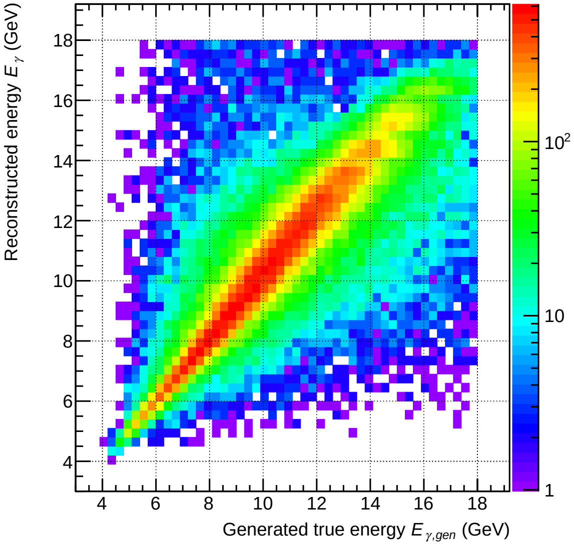
- The spectrometers are placed at *z* = -36.4 m, clearance in vertical *y* between up and down detectors is 120 mm
- Both spectrometer detectors are inclined at an angle along *x* for its front face to be perpendicular to the end of dipole magnet



- Front area for each detector is 200×200 mm^2
- Tracking layers, A, B and C are spaced by 100 mm from each other
- cal is a tungsten-scintillator calorimeter (not used for reconstruction)
- Photon exit window was extended to ±2 mrad to get photons at larger angles

Photon reconstruction in the spectrometer

- The up and down layers measure local track position and angles, x_{up}, x_{down}, y_{up}, y_{down} and $\theta_{x,\mathrm{up}}$, $\theta_{x,\mathrm{down}}$, $\theta_{y,\mathrm{up}}$ and $\theta_{y,\mathrm{down}}$ (8 quantities)
- The ML algorithm relates these 8 tracking quantities to bremsstrahlung photon energy E_γ and polar and azimuthal angles θ_γ and ϕ_γ
- Reconstructed photon energy is compared to the true generated photon energy in the plot



Photon polar and azimuthal angle

- Reconstructed angles are compared to the true generated angles
- The true angles refer to the values before the beam effects were applied in event generator
- Angular reconstruction is limited by the divergence because of small polar angles

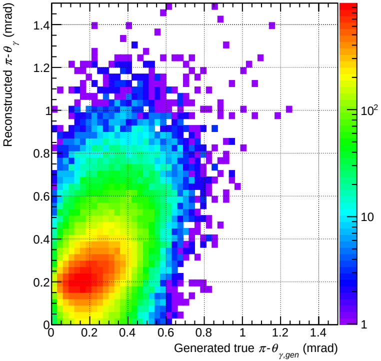


Figure: Polar angle

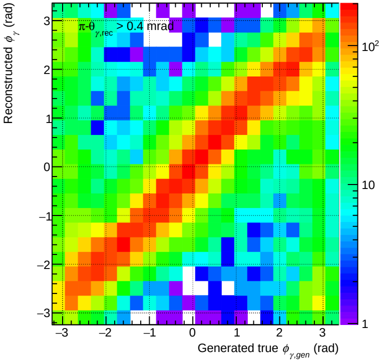


Figure: Azimuthal angle

Angular reconstruction is still important to control the actual aperture and for systematic checks

Summary

- Ongoing integration into the beam pipe layout
- Considerations of vacuum impose limits on maximal detector dimensions
- Requirements on impedance are fulfilled by an angle of detector planes and conductive foils in downstream direction
- Immediate needs include fixing transport in magnetic field in DD4hep
- Other task is realistic tracking without help from MC truth, as was used here
- Photoproduction electron should be embedded in pile-up bremsstrahlung interaction to test the background suppression
- The same holds for spectrometer and direct photon detector

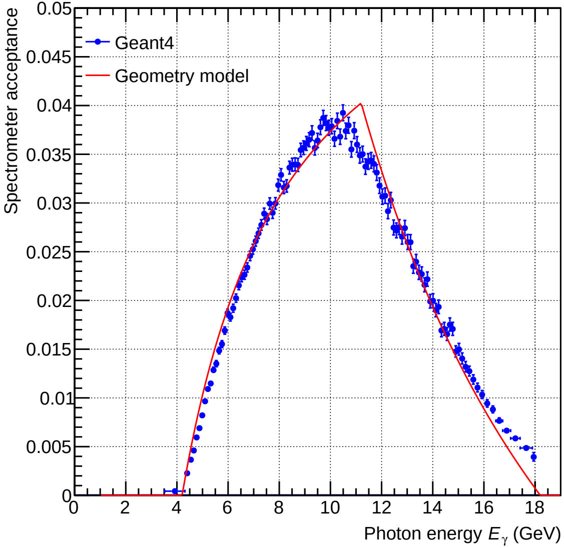
Backup

Reconstruction in low-Q^2 taggers

- Each tagger (its 3 layers) measures track position on its plane, x and y and track angles in the respective directions, θ_x and θ_y
- Machine learning algorithm relates measured quantities x, y, θ_x and θ_y with electron energy, polar angle and azimuthal angle, E_e, θ_e and ϕ_e
- The algorithm was trained using sample with uniform energy and angular distribution
- During reconstruction the algorithm provides electron E_e, θ_e and ϕ_e for a set of measured x, y, θ_x and θ_y as obtained for a given track in tagger
- The reconstruction was applied to quasi-real photoproduction and Pythia 6
- Machine learning implementation is here:
  github.com/adamjaro/lmon/blob/master/src/EThetaPhiReco.cxx
  github.com/adamjaro/lmon/blob/master/include/EThetaPhiReco.h

Spectrometer acceptance

- Coincidence from both up and down detectors is required; the acceptance as a function of bremsstrahlung photon energy is shown on the right
- The criteria for each up or down detector are:
  - The track passing each A, B and C layers has at least 100 MeV and is electron in up detector and positron in down detector (the only help from truth mc)
  - Energy deposited in the calorimeter is at least 20 MeV
- Geometry model refers to similar procedure in ZEUS paper in NIMA 565 (2006) 572-588



Reconstruction procedure in spectrometer

- The set of 8 measured tracking quantities, x_{up}, x_{down}, y_{up}, y_{down} and $\theta_{x,\mathrm{up}}$, $\theta_{x,\mathrm{down}}$, $\theta_{y,\mathrm{up}}$ and $\theta_{y,\mathrm{down}}$ is used to obtain bremsstrahlung photon energy E_γ and polar and azimuthal angles θ_γ and ϕ_γ
- Machine learning algorithm was used to relate these 8 tracking quantities to photon kinematics given as E_γ, θ_γ and ϕ_γ
- The algorithm was trained using a sample of 200M photons with uniform energy and angular distribution
- Reconstruction using the trained algorithm was then applied to a sample of physics bremsstrahlung photons generated by GETaLM event generator following the Lifshitz parametrization
- During reconstruction the algorithm provides the photon energy E_γ and angles θ_γ and ϕ_γ for a given set of measured track positions x_{up}, x_{down}, y_{up}, y_{down} and angles $\theta_{x,\mathrm{up}}$, $\theta_{x,\mathrm{down}}$, $\theta_{y,\mathrm{up}}$ and $\theta_{y,\mathrm{down}}$
- Calorimeter deposited energy is not considered here for the reconstruction
- Performance will be shown next for the reconstructed photon E_γ, θ_γ and ϕ_γ
- The same ML algorithm was used for electron reconstruction in low-Q^2 taggers